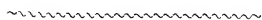


PROCEEDINGS

OF

THE ROYAL SOCIETY.



April 20, 1882.

THE PRESIDENT in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The President condoled with the Meeting on the great loss which Science and the Society had sustained through the decease of their distinguished Fellow, Charles Darwin; and mentioned that a proposal for interment in Westminster Abbey had been made to the family of the deceased and to the Dean, which he trusted would be brought to pass.

The following Papers were read:—

- I. “On the Formation of Ripplemark.” By ARTHUR ROOPE HUNT, M.A., F.G.S. Communicated by Lord RAYLEIGH, F.R.S. Received March 28, 1882. Read April 20.

Fossil ripplemarks are often appealed to by geologists as evidence that the winds and waves that formed them cannot have differed much in intensity from those that produce similar corrugations on the sands of our modern beaches; but, although considerable value is attached to the evidence afforded by these relics of ancient seas, authorities differ much as to their origin.

According to Sir Charles Lyell ripplemark originates in the “drifting of materials along the bottom of the water,” and “is usually an indication of a sea beach, or of water from 6 to 10 feet in depth, though this rule he proceeds to say is not without exception, as recent ripplemarks have been observed at the depth of 60 or 70 feet. The crossing of two sets of ripples the distinguished author ascribes to the new direction in which the waves are thrown on the shore consequent on a

change of wind ("Elements of Geology," 6th edition, p. 19). Mr. J. Beete Jukes, in the first edition of his "Manual of Geology," states, that current mark or ripple "is produced on the sea beach, not in consequence of the ripple of the wave impressing its own form on the sand below, which would be an impossibility, but because the moving current of water as the tide advances or recedes produces on the surface of the sand below the same form as the moving current of air produces on the surface of the water above. A rippled surface, therefore, to a rock is no proof of its having been necessarily formed in shallow water, though rippled surfaces are perhaps more frequently formed there, but simply a proof of a current in the water sufficient to move the sand at its bottom gently along, at whatever depth that bottom may be from the surface of the water." Speaking of fossil ripplemarks the same author states that the distance from crest to crest of the ridges varies from half an inch to eight or ten inches, with a proportionate variation in depth between them (Jukes' "Man. Geol.," p. 172). The article on ripplemark is recast in the third edition, edited by Dr. Geikie and published in 1872, but the views expressed therein are the same.

Monsieur Delesse goes far beyond the authorities referred to above, as on the authority of Commandant Cialdi, he states that the movement of waves can displace fine sand at a depth of 200 metres in the ocean, and (without giving his authority for the statement) that the undulation of the sea is evidenced by ripplemarks on muddy bottoms down to a depth of 188 metres ("Lithologie du fonds des Mers," 1871, pp. 110, 111). More recently, Mr. G. H. Darwin has stated that one of the conditions of the formation of many ripples is a great ebb and flow of the tides ("Nature," vol. xxv, p. 214).

It will be seen from the authorities cited above, that the phenomenon known as ripplemark is variously ascribed to the action of currents, and to the undulation of waves, and that whereas by some it is considered the result of tidal action in shallow water, by others it is attributed to the action of waves down to the great depth of upwards of 100 fathoms.

I shall endeavour in the present paper to prove that ripplemarks formed under water are, as a rule, completely independent of the rise and fall of tides, of tidal currents, and of sea beaches; and that they have little in common with the current mark, that owes its origin either to a continuous current of air or of water.

For some years past I have neglected no opportunity of making observations on the action of storm waves on the bottom of Torbay, and of collecting evidence as to the action of waves and currents on the bottom of the English Channel. To Lord Rayleigh I must express my indebtedness for having examined my evidence of submarine wave action from a mathematical standpoint, and for having called my

attention to the fact that waves, if they affect the bottom at all, do so by setting up alternate currents;* and that, though at great depths the action is very small, theoretically it has no limit.

Having observed that ripplemarks are commonly better preserved in pools between tidemarks than on those parts of the tidal strand left dry at low tide, and that the bottoms of these pools must be in some measure protected from the continuous currents that are commonly supposed to produce the ripplemarks, it seemed to me probable that they were produced by the alternate action of waves described to me by Lord Rayleigh.

One fine and almost calm day in the summer of 1881, being at Broadsands in Torbay, and seeing that the strand was covered with ripplemarks, I proceeded to watch carefully the action of the water with a view of ascertaining, if possible, the process of their formation. Floating in my boat a few yards from the shore in about 18 inches of water, I narrowly scanned the effect of the very gentle swell that was breaking on the beach. I observed that a small shell lying in one of the furrows instead of being steadily washed shorewards by the incoming waves, was washed backwards and forwards from one furrow to another; sometimes it would stop on the intervening ridge, and so for the moment help to build it up; at others it would fall over into the furrow towards which for the moment it was being propelled, but in no case did it show any tendency to travel continuously in any particular direction along the bottom.

On a subsequent occasion, having to land on the beach at Paignton, and seeing the ripplemarks well developed, I again carefully watched them seawards. At a point where the bottom was too indistinct for me to observe its condition, I could distinguish fragments of seaweed gently moving backwards and forwards in the direction of the beach, and at right angles to the ripplemark where last visible. This observation was unexpected, as it proved a gentle swinging motion of the water in the vicinity of the shore, when the surface motion was so slight as not to interfere with my landing on a flat open beach from a very small boat.

On the 19th October, 1881, there was a strong south-easterly gale in Torbay, and the waves rolled on to the Meadfoot Sands at the rate of $7\frac{1}{2}$ per minute. The distance between the southern point of an outlying islet known as the Shag Rock and the rocks at the western end of Meadfoot Sands (two points in line with the direction of propagation of the waves), 275 yards by the chart, was covered by exactly three waves, so that each one must have measured 275 feet from crest to crest. In midbay this length was probably exceeded. As from the manifest turbidity of the water, the bottom was unques-

* "Trans. Dev. Assoc.," vol. x, p. 191 (1878).

tionably much disturbed, I looked forward with interest to ascertaining by the dredge what effect these waves of known dimensions had had on the bottom. On the 31st of October, nearly a fortnight after the gale, I had an opportunity of going out for this purpose, and in places, in 6 fathoms (at low water spring tides), where the bottom is usually a soft muddy sand that clogs the dredge in a few minutes, the ground proved to be quite hard. One haul of the dredge brought up a *Buccinum* shell, with the mollusc inside it dead, and two dead ascidians; and another in midbay, though with 30 fathoms of rope, produced not a shell or a particle of the usual muddy sand, but only a few red seaweeds that must have come from a distance. Never before in my experience had I found the ground so hard in midbay, nor dredged dead molluscs and ascidians. On the 11th November the ground was still very hard, both the dredge and a fishing-lead tied to a line bumping along as though over ridges. On the 8th December, more than six weeks after the gale, I again tried the same spot in midbay that proved so hard on the 31st October: it had now returned to its normal state, and the dredge brought up the usual muddy sand. These dredgings tended to show that the bottom had been violently agitated by the storm, and that as the seas subsided it had become strongly ripple marked. Why it should change from soft to hard and back again to soft is not very clear, but there is no doubt as to the fact.

It may be objected that as fossil ripplemarks have been said to be limited to 10 inches, a dredge would scarcely detect modern ripples if not larger than that; but there is no doubt that modern ripplemarks occasionally far exceed these dimensions. I have myself seen them formed in Brighthouse Bay, on the coast of Kirkcudbright, fully $2\frac{1}{2}$ feet from crest to crest, and deep in proportion.*

* Since writing the above my attention has been directed to the following important, though quite incidental, descriptions of wave-marks on the Goodwin Sands by the Rev. John Gilmore, in his book intitled "Storm Warriors, or Lifeboat Work on the Goodwin Sands." They are as follows:—

"On the Goodwins where the force of the sea is in every way multiplied and the waves break and the tide rushes with tenfold power, the little sand-ripples of the smoother shore become ridges of two or three feet high. It is on these ridges that the lifeboat so continually grounds. As the tide rises she is swept from one to the other by the long sweeping waves; she is swung round and round in the swirl of the cross seas and rapid tide, thumping and jerking heavily each time that she strands."—*Op. cit.*, p. 109.

"... The heavy seas have driven the sands into high ridges, and the gullies between these are waist-deep and full of running water with the sand soft and quick at the bottom; through these deep gullies the men have to wade."—*Op. cit.*, p. 215.

"... At last all are on board, but they cannot yet leave the sands, they must wait until the water is high enough to float the lifeboat over the ridge which surrounds her."—*Op. cit.*, p. 222.

Feeling satisfied that the bottom of Torbay in about 6 fathoms at low water spring tides was rippled by the swells following the October gales, I proceeded to construct a small tank, about 9 feet by 3 feet by 1 foot, in order to prove experimentally whether subaqueous ripple-marks could be formed at will, and to what extent their dimensions could be controlled.

Working on this small scale I experienced no difficulty in forming good ripplemarks varying in size from $\frac{1}{8}$ th of an inch to 4 inches from crest to crest. The tank was commonly arranged as follows:—The sand was so piled up at one end that the waves when generated would quickly tear down what they wanted for a strand on which to break, and from that strand outwards the amount of sand used was regulated by the depth of water required for each experiment. The further end of the tank where the waves were generated was kept free from sand so as to have the greatest available depth of water, generally about 9 inches. The waves were generated by a vertical displacement of the water, either by means of a V-shaped trough worked by hand or by means of a semi-cylindrical block of wood worked by a small model steam-engine.

The following five experiments will show how very rapidly ripple-marks can be formed.

(1.) Waves 60 per minute, height trough to crest about $1\frac{1}{2}$ inches. Result, $1\frac{1}{2}$ inch ripples in water 2 and 3 inches in depth.

(2.) Waves 115 per minute, height not measured. Result, $\frac{1}{2}$ inch ripples well developed in 2 inch water, and discernible down to $3\frac{1}{2}$ inches deep.

(3.) Waves 23 per minute, height not measured. Result, the small ripplemarks now effaced and replaced by others $1\frac{1}{2}$ inch in size.

In the above cases the experiments lasted exactly one minute each.

(4.) Agitated the water at the centre of the tank, gradually getting up an even swing of 13 to the minute. The time was taken after the water was in full swing, and the experiment may have lasted one minute and a half. Result, ripplemarks were now more or less developed over the whole bottom, the largest being 3 inches in length.

(5.) The beach was now removed and the sand levelled over the whole tank. The water was disturbed with an even swing as much as possible. It rebounded from end to end, and dashed over the two ends, which in this experiment were 5 inches above the water-line. The sand being completely stirred up was left a night to settle, and the next day the water being still turbid, it was drawn off. Result, the bottom proved to be strongly but unevenly rippled all over with ripples varying in size from less than 1 inch to over 4 inches; the greatest depression being about $\frac{1}{2}$ inch from trough to crest. In one case a set of ripples had been formed exactly at right angles to a larger set which was nearly obliterated by them.

In a paper published in 1859,* Mr. H. C. Sorby, F.R.S., showed how currents flowing in one direction form the kind of ripplemark or current mark termed by him "rippledrift;" but, as the currents that form the ripplemarks on the sea-shore are alternate and set up no drifting action in the ordinary sense of the word, it seems to me important to distinguish between the current mark that can be seen occasionally on the bottom of running water and the marine ripplemark that differs from it, both as to its origin and as to its effect. I believe the symmetrical ripplemark of the sea-shore cannot be formed by a continuous current, and that whether recent or fossil it is as certain an indication of an alternate wave current as the "ripple-drift" is of a continuous current. Both of these current marks can be readily formed in a round tub of water with a little sand on the bottom. If the water be rotated constant-current ripples or "ripple-drift" are formed: if the tub be carefully rocked symmetrical alternate-current ripples shortly appear.

My experiments having satisfied my mind that ripplemark can be formed on sandy bottoms by a slight oscillation of the water, I took an early opportunity of visiting the shores of Torbay, between Torquay and Livermead Point, for the purpose of ascertaining definitely whether the size and direction of natural ripplemarks bore any relation to the force and direction of the wind. The day selected was the 21st January, 1882, after a week of calm weather, accompanied by the highest recorded rise of the barometer in Britain. There had been very little wind for days, but a slight swell on the 20th, and very low tides promised a well-rippled beach for the 21st.

On reaching the sands under Sulyarde Terrace, I observed that they were covered with the most perfect and symmetrical ripplemarks from the south-west, the only direction from which a swell from the sea could reach them, as the new pier protects that part of the shore from waves coming from any point more to the southward. Proceeding thence along the sands in a westerly direction, I saw the ripplemarks gradually getting effaced, until at a point opposite the Belgrave Road they were completely obliterated, excepting in pools and depressions in the sand, where they were as perfect as before. At this point, which is not protected by the pier and is exposed to the open sea, the direction of the ripples was south-south-east (S.S.E.). In one of the pools they measured 6 inches from ridge to ridge, and the ridges were sharply defined and perfectly angular. Under the Corbons, on a little beach between the rocks, there were some very perfect ripples 13 inches between ridges, and $1\frac{3}{4}$ inches in vertical height. Passing on to the next beach, Livermead Sands, I found a large area of sand covered by perfect 6-inch ripples from the south-east, which in their turn were

* "On the Structures produced by the Currents present during the Deposition of Stratified Rocks." "The Geologist," 1859, p. 137.

crossed by 2-inch ripples from the north-east. The explanation of these cross ripples was clear. A portion of the sands was raised to such an extent that on the tide retiring an island was formed for a short time. The 6-inch ripples owed their origin to the swell from the south-east, whilst all the sands were covered, whereas the 2-inch ripples owed theirs to the water running in and out at the back of the emerged sandbank at right angles to the direction of the main swell.

On the 23rd January I went over the same ground again, with the following results. Under Sulyarde Terrace I again found the ripples coming from the south-west. Under the Belgrave Road their direction was due south, well developed on flats, but obliterated on slopes towards the sea. In the "submerged forest" clay was a round pool, 15 feet in diameter, with its bottom covered with 5-inch ripples from the south-by-east (S.b.E.), crossed by $1\frac{1}{2}$ -inch ripples from east-by-north (E.b.N.) This was owing to the southern side of the pool drying before the eastern. On a small beach between the rocks, at the western ends of the sands, under the Great Western Hotel, the ripples, of different sizes but averaging about 3 inches, came as nearly as possible from the south-east. Under the Corbons Head I again found the large ripples, the largest being 14 inches between ridges and 2 inches high; they were composed of sand, coarser than at Torre Abbey, and broken shells. At the east end of Livermead Sands there was again an extensive low bank, with pools on the landward side. On the bank were 3-inch ripples from the S.E., gradually obliterated towards low-water mark, where the sand was quite smooth. One of the back pools was covered with perfect ripples, varying in size from 2 inches (by estimation, as they were inaccessible) to 17 inches by measurement. Direction of all, south-east. The landward slope of the sand-bank was covered with ripples from the south-east, crossed at different places by others from the north-eastward and eastward. At the west end of the Livermead Sands were some large, but not perfectly preserved, ripples, 22 inches long between ridges and over 3 inches high.

These observations prove that ripplemarks are independent of the direct action of wind, for on two separate occasions the Torre Abbey and Livermead Sands could furnish at the same time ripples coming from all points, from south-west to north-east (on the eastern side). They also show what a complicated problem is that of the size of ripplemarks, and how little the geologist can gather from mere size, for on the same beach were ripples ranging from $1\frac{1}{2}$ inches to 22 inches, and in one small pool almost every size was represented between 2 inches and 17 inches.

Having shown that the conditions requisite for the formation of ripplemarks are alternating currents on a mobile bottom, I will proceed to show that there is good evidence that alternating currents and

therefore ripplemarks, occur at much greater depths than is commonly supposed. To do this I must prove that there is occasionally motion at the bottom of the sea, and that this motion does not arise from continuous, but from alternate, currents.

I will commence with a simple case, one that I have studied for many years, viz., Torbay. This bay is an inlet rather more than 4 miles in breadth and over 3 in depth, carved out of Devonian and Triassic rocks of varying degrees of hardness, and open to the south-east. In its centre there is a level area of about 5 square miles, round which a line can be drawn so as to include every 6-fathom sounding and to exclude every other. The bottom over this area consists superficially of a very fine sand, of which a sample taken at any spot will represent the whole. After heavy easterly gales, as has been already stated, the water is very turbid, and the slushy bottom occasionally becomes harder. The level surface of the bottom, the uniformity of its material, the alteration in its character after gales, and the turbidity of the water, all point to one conclusion, viz., that storm waves materially affect the bed of the bay. To the intensity of this action the fauna also bears witness. Shells that inhabit the 5- and 6-fathom areas, such as *Thracia convexa* and *Cardium aculeatum* are occasionally washed ashore from considerable distances. A valve of a full-grown *Thracia convexa*, picked up on Paignton Sands, was some 3,000 yards distant from the only spot where, to my knowledge, that mollusc has been taken alive in Torbay. Specimens of *Cardium aculeatum* are occasionally washed ashore and sometimes in vast numbers, but they are invariably denuded of their spines. Even though not washed ashore, thousands are sometimes rolled and killed in the 6-fathom area, whilst those that survive testify to the severity of the ordeal passed through by the damage done to their shells, and by the repairs effected. The contrast between the old shell denuded of spines and the rim of new growth with spines perfect is often very marked. In one specimen in the museum of the Torquay Natural History Society half the shell is quite smooth and the other half furnished with perfect spines. There are very few genera of molluscs, whether bivalve or univalve, that inhabit the 6-fathom area of Torbay, provided their shells are not internal, whose shells do not occasionally bear upon them the marks of a struggle for existence, more or less severe, with the storm waves of Torbay.

The marks of damage to which I allude, when severe, cannot be mistaken for lines indicating cessation of growth from change of temperature, lack of food, or other such cause; they do not indicate merely a check in the formation of new shell, but in very many cases the destruction of the old. Nor are these marks confined to individual shells alone, for they are often common to whole colonies together. If a single cardium be found, with the new shell growing

out from under the old, owing to the edges having been too much damaged to admit of continuous shell formation, it may be contended that the individual mollusc had met with some special accident, but when hundreds of cockles are dredged together, showing the same marks of damage, repair, and subsequent growth, it is impossible to escape from the conclusion that they were all subjected together to some serious disturbance of their beds.

In a paper read to the Devonshire Association, in 1878,* I showed, from the data furnished me by Lord Rayleigh, that on the 6-fathom area in Torbay a wave 300 feet long and three feet above mean level, if such ever occurred, would cause an alternating current at the bottom with a maximum speed of 3 feet per second. On two occasions (22nd October, 1880, and 4th April, 1881), since then, during easterly gales, I have observed waves with a period of $8\frac{1}{2}$ seconds, and on one occasion, viz., on the 19th October, 1881, waves with a period of 8 seconds. On the last occasion, as has been already stated, I was able, by means of known marks to measure both the wave-length and speed. The length where measured proved to be 275 feet and the speed 660 yards per minute, but as the waves, before reaching the shore had to traverse about 1,000 yards of water less than 6 fathoms in depth, their length in midbay probably did not fall short of 300 feet. Their height I had no means of measuring, but at the low computation of one-thirtieth the wave-length, it would be 10 feet, or 5 feet above mean level.†

Leaving Torbay, with its comparatively shallow water, I will proceed to examine the evidence of disturbance at the bottom, in the deeper waters of the English Channel. The evidence at hand is of a varied nature, and includes the testimony borne by the character of the bottom itself, by valves of shells and other inanimate objects dredged up, by the character of the fauna, and by experienced fishermen.

In April, 1880, a large earthenware jar was brought up in the trawl of the Brixham smack "Pelican" about 20 miles south-east of the Start point, where the depth, according to the chart, is about 36 or 37 fathoms.

Mr. Pengelly, F.R.S., has described this jar with its contents (as received at Torquay) of half-a-pint of sand and gravel, and from the fact that "the whole surface of the bottom, as well as about fully one-half of the entire lateral surface" was covered with marine organisms and that the jar was not abraded, arrived at the conclusion "that the

* "Trans. Dev. Assoc.," vol. x, p. 192.

† On the 25th October, when the weather had moderated, H.M.S. "Inflexible" left Plymouth for Gibraltar. On her arrival there, Captain Fisher reported having encountered waves 300 feet in length and 24 feet in height.—("Western Morning News.")

jar underwent little or no movement after reaching the sea bottom that there was very little movement of the gravel there," and that "of storm-wave movement there could have been none, and of tidal-wave movement very little."* This reasoning seemed to me very difficult to turn aside, until I was told by one of the crew of the "Pelican" that the jar contained a quantity of gravel, and that it could scarcely have moved, being so weighted. This point seems to me of so much importance that I recently requested Mr. Hayden, the captain of the "Pelican," who did not remember the circumstance, to make further enquiry of the second hand, who had given me the information. He replied as follows:—

"Brixham, Feb. 16th, 1882.

"DEAR SIR,—I have been speaking to Mr. Dyer about the jar that we caught, and he says he remembers very well about it, and that it was nearly full of very dirty gravel; and I think the jar did not move on the bottom; when the bottom gets disturbed it must have washed in the jar. Please to excuse my writing to you only I thought you would like to know. I have got a few shells, and I hope by the time Mr. Baynes comes over again I shall have a basketful.—From J. HAYDEN, Master of smack 'Pelican.'

"I think the gravel must have been in the jar a very long time, owing to its being so dirty."

I have ascertained by measurement that when the jar is laid on its side, the lower internal lip of the neck is $9\frac{1}{2}$ inches above the surface on which the jar is resting. The internal diameter of the neck is less than 2 inches. Through this small hole the gravel that filled it must have found its way; but for it to do this, it was absolutely necessary, either by the motion of the empty jar, or of the gravel, or of both, to get rid of the $9\frac{1}{2}$ inches of space that, during times of quiescence, lay between them.

Then, again, when found, the jar was half buried in gravel, and this fact also proves sufficient motion at the bottom in 36 fathoms of water to move gravel whose character has been described by Mr. Pengelly, from the sample left in the jar, as "sub-angular and rounded stones, the largest of which scarcely exceeded a hazel nut in size." The fact that the jar was half-buried is of importance, as it proves motion of the bottom itself, and is not liable to the objection that might possibly be raised (though there is strong evidence to the contrary) that the jar was full of gravel when lost.

The evidence of motion afforded by the character of the marine fauna, if considered in detail, would require more space than can be

* "Trans. Dev. Assoc.," vol. xii, p. 76.

afforded in the present paper. A very cursory glance at it must suffice.

The character of the fauna of the littoral zone is such that it can be seen at a glance that the chief enemy that has to be contended against is the wash of the waves. Molluscs and crustaceans living on rocks are specially adapted to cling tightly to those rocks, whereas those living on sand have the power of burrowing in the sand. Where the ground is solid, as in the case of rocks, the animals living on it trust to their powers of holding on or of boring into it; where the ground is unstable the animals that frequent it trust to their powers of rapidly shifting their positions. Of the former class the limpet is a good example; of the latter the common razor fish. But if the molluscs of the littoral zone are specially adapted to resist the wash of the waves that would drive them high and dry on shore, it is equally true that many of those living in the laminarian and coralline zones are wonderfully provided against their special danger, viz., the alternate swing of the waves on the bottom. Living as they do continuously under water, their shells are free to assume the most elaborate sculpture and form, from which the littoral shells are precluded, owing to a compulsory cessation of growth twice a day by retreat of the tide. In many cases the development of the lip, or of the sculpture in the form of spines, supplies exactly what the animal wants, viz., a broad base for a sandy bottom. By the kindness of the Rev. A. Cook I have been able to experiment with a few winged and spined shells from different parts of the world. One experiment with a *Murex monodon* from Australia, a *Pteroceras lambis* from the East Indies, a *Strombus tricornis* from the Red Sea, and four specimens of *Aporrhais pes pelecani* from Torbay was very instructive. Placing them all on their backs in my tank, I succeeded on one occasion in fifteen seconds in restoring them all to their proper positions, simply by swinging the water in the tank. Owing to the weight of the foreign shells some difficulty was experienced in getting them in motion, and moreover, with the exception of the *Aporrhais* and *Pteroceras*, they were not particularly suitable for the experiment, as they had not wings or spines very largely developed.

In the case of the extremely long spined murex, *M. tenuispina*, though the spines offer great resistance to the animal being overturned, they do not afford any assistance to the animal to recover its balance when once it has lost it. In the best examples of winged and spinous shells, such as *Aporrhais* and *Pteroceras*, the alternate current requisite to upset them is very much more powerful than one sufficient to restore them to their normal position.

As *Aporrhais pes pelecani* is a beautiful instance of a gasteropod proof against moderate wave action, so the common *Pecten maximus* is a good example of like protection among the bivalves. Owing to one

valve being flat and the other curved it follows that a slight disturbance of the water will place it in a stable position. I find that it is quite easy to roll over a full grown *P. maximus* in my small tank if resting on the convex valve, but to dislodge it when resting on the flat valve transcends the power of any current I can bring to bear upon it. Owing to the rejection by naturalists of the theory of submarine wave-motion, the fact that certain parasitic sea anemones, such as *Adamsia palliata* and *Sagartia parasitica*, commonly choose a shell tenanted by a hermit crab (*pagurus*) has been a matter of some perplexity. But, given the submarine wave action, and the problem finds its solution. The crab keeps the shell from rolling, and the anemone from being killed. I have taken many young specimens of *Sagartia parasitica* on living shells of *Turritella terebra*, but from the state in which I have seen shells of this mollusc damaged by rolling, I cannot conceive the possibility of the young anemones having much chance of surviving the first severe storm. The protection afforded by hermit crabs is no matter of fancy, as anyone can see by gently rocking the water in an aquarium, tenanted by hermit crabs, on a sandy bottom. If the crab happens to be in his shell, the first impulse is to dart out his legs and claws, and hold on to the sand on as broad a base as possible. His cousin, the swimming crab (*portunus*), under similar circumstances will burrow, or, if finally dislodged by the shifting of the sand, will dart upwards into the water to escape the commotion. Many of the small fishes, crustaceans, and molluscs that frequent the 6-fathom area of Torbay seem quite on their guard, and prompt in their action when disturbed by oscillating currents in a small aquarium.

Want of space precludes the possibility of pursuing this branch of my subject further, and compels me to turn to the next question, viz., the evidence afforded by the shells of molluscs of motion on the sea floor.

I have assumed that wave action on the bottom of Torbay will scarcely be denied, and have passed lightly the evidence of the Torbay shells. It now remains to consider the evidence of those found in deeper waters. Among the shells sent me by fishermen who have taken them on the oyster ground off the mouth of Torbay, in about 15 fathoms, have been several specimens of *Trochus granulatus*, an inhabitant of the coralline zone. On a careful examination of eight of these shells, it appears that not one of them has escaped rough treatment more than once in the course of its life, and that one of them has had to repair serious damages nine times, over and above any slight abrasion that did not suffice to interfere with the sculpture and regular growth of the shell. On the 10th February, 1882, I bought three scallops (*Pecten maximus*) at a fishmonger's shop, where I was informed they had all been taken off Berry Head on the

previous day. Two of them were nearly the same size and showed several marks of interrupted growth; one of the marks was quite unmistakeable, when the shells were about $1\frac{1}{2}$ inches long. I measured each of the convex valves of these pectens independently, recording the size of each when the interruptions to growth occurred. The lengths of each were as follows, measured in inches and sixteenths:—

			No. 1.	No. 2.
Growth checked when the length of shell was			$1\frac{7}{16}$	$1\frac{1}{2}$
"	"	"	$2\frac{10}{16}$	$2\frac{5}{16}$
"	"	"	$3\frac{1}{8}$	$3\frac{1}{4}$
"	"	"	$3\frac{1}{2}$	$3\frac{5}{8}$
"	"	"	$3\frac{11}{16}$	$3\frac{13}{16}$
"	"	"	4	4
"	"	"	$4\frac{1}{4}$	$4\frac{5}{16}$
Total length			$4\frac{5}{16}$	$4\frac{7}{16}$

The interest in these pectens lies in the correspondence of their lines of arrested growth, which have clearly been caused by some external agent common to both shells, and are not due to any idiosyncrasy. Taken separately both shells are inferior as examples of arrested growth to the specimen of *Pecten maximus* figured by Mr. Jeffreys on Plate XXV of his "British Conchology."

On the 3rd of March I received the parcel of shells referred to in Hayden's letter. They were taken whilst the crew of the "Pelican" were pursuing their ordinary avocation of fishing, and their collection was spread over a considerable time. The exact locality whence came each shell cannot of course be specified, but it so happens that with the shells I received fragments of three of the Channel stones, which the crew of the "Pelican" have been in the habit of sending me for some years past. These stones give us a clue as to the depth of water where the vessel had been fishing. One stone was taken 18 or 20 miles S.S.E. of the Start, another 20 miles S. of the Eddystone, and the third 15 miles S.E. of the Start. The depth of water at the places indicated is (according to the chart) 38, 41, and 36 fathoms respectively, giving an average of over 38 fathoms. The majority of these shells bear on them marks of arrested growth, not, as a rule, so decided as those from shallower water, but in many cases quite unmistakeable. Some details of the collection are given in the following table:—

	Showing arrested growth.	Not showing arrested growth or doubtful.	Total number of specimens.
<i>Pecten opercularis</i>	22	3	25
<i>Penna rudis</i>	6	..	6
<i>Cardium echinatum</i>	2	..	2
<i>Cardium norvegicum</i>	2	2	4
<i>Cyprina islandica</i>	2	2	4
<i>Tapes virgineus</i>	1	..	1
<i>Solen ensis</i>	..	1	1
<i>Capulus hungaricus</i>	8	6	14
<i>Trochus granulatus</i>	2	1	3
<i>Trochus zizyphinus</i>	1	..	1
<i>Turritella terebra</i>	..	1	1
<i>Natica catena</i>	..	1	1
<i>Buccinum undatum</i>	4	2	6
<i>Fusus gracilis</i>	3	5	8
<i>Fusus buccinatus</i>	..	2	2
<i>Scaphander lignarius</i>	5	1	6
	58	27	85

Without pretending to affirm that all the cases of arrested growth are due to wave action, it seems to me a significant fact that out of a miscellaneous parcel of shells from the Channel fishing ground, 68 per cent. should show signs of damage caused by some agent external to themselves. Notes on the above shells would be out of place here, but it may be pointed out that the oftentimes damaged state of such a sedentary mollusc as *Capulus hungaricus* may be owing to the fact that it is frequently found attached to pinna, and that pinna is one of the shells frequently found damaged. The frontispiece to Mr. Gwyn Jeffreys' second volume of his "British Conchology" depicts a pinna that has received a decided check to its growth, but by no means a severe one.

Having shown that disturbance of the bottom is evidenced at depths of a few fathoms by the visible turbidity of the water, and at greater depths by the damage done to shells and by the special provision in their habits and structure to withstand such action, I now turn to the evidence of nautical men as to the existence of submarine wave action, and as to the actual dangers to which vessels are exposed owing to the effects of such action. My first witness will be G. Hayden, the skipper of the Brixham trawler "Pelican," and though his evidence amounts to little more than the expression of his opinion, it is the opinion of a man thoroughly acquainted with the subject under consideration. I submitted to him the following queries, to which he appended his replies and attested them by his signature :—

(1.) Do you think the bottom on the fishing grounds off the Start

is affected by heavy gales?—Yes; I think the ground is very much disturbed by heavy gales.

(2.) Do you find the fish act differently after gales, *i.e.*, swim higher or lie closer?—I think that fish are affected during the gale, but that after the gale they resume their usual habits.

Captain Kiddle, of the White Star steamer "Celtic," writes ("Nat.," vol. 13, p. 108) that "On George's Shoals, off Nantucket, during a heavy gale, the New York pilots and masters of coasting vessels assert that sand is frequently left on deck after a sea has broken on board, although the depth of water may be 12 or 14 fathoms. . . . The shortness of the sea on the banks of Newfoundland, where the soundings are from 30 to 50 fathoms, is noticed by all the navigators of the Western Atlantic, as it reduces the speed of an ocean steamer more than the heavier waves of deeper water will do. . . . In the gulf stream north of the Straits of Bemine, after a "norther" has blown a few hours, the surface of the sea is covered with lanes of weed, although only a few patches might have been seen before the commencement of the gale."

Before passing on, it will be well to point out that the disturbance of the bottom on the banks of Newfoundland has strong zoological evidence in its favour. Mr. J. Gwyn Jeffreys, F.R.S., writes as follows of the bivalve *Mya truncata*. "The cod on the North American fishing banks seem to be equally fond of this mollusc; but it is not so easy to say how they procure it. *Mya truncata* is often buried from 8 to 10 inches below the sea-bottom; and it does not seem to be capable of changing its habitation."*

Now, I have taken this very mollusc alive in Torbay after easterly gales, and I have taken flat fish that have been feeding on *Cardium aculeatum* killed by heavy seas. If channel seas can dislodge *Mya truncata* from its deep burrow in Torbay, there is every probability that Atlantic seas will dislodge it occasionally on the banks of Newfoundland. The seaman's assertion solves the problem that has perplexed the naturalist, and the fact observed and recorded by the naturalist strongly corroborates the statement and conclusion of the sailor.

The evidence hitherto adduced goes far to prove that at depths of about 40 fathoms in the English Channel and of 50 on the Banks or Newfoundland there is not only motion at the bottom, but strong motion, far exceeding the gentle oscillation of the water that is sufficient to ripple a sandy sea-bed. According to Sir Charles Lyell, quoting from the "Encyclopædia Britannica," a current of but 6 inches per second will suffice to raise fine sand.† This no doubt refers to constant currents, as it is far in excess of what is sufficient in the case of alter-

* "British Conchology," vol. iii, p. 69.

† "Principles of Geology," vol. i, p. 348, 10th edition.

nate currents. I found on trial with a small glass aquarium, containing fine blown sand, that an alternating current passing over a space of 2 inches 120 times per minute strongly rippled the sand with ripples varying in size from one inch downwards. Thus an average speed of 4 inches per second sufficed to form ripples so large as one inch from ridge to ridge. It is clear that a much slower current would still suffice to produce smaller ripples.

It would be a matter of great interest to know at what depth an Atlantic wave would set up an alternating current of 4 inches per second, for, whatever the depth, it would fall short of that at which ripplemarks might be formed.

Although the question of the relation of current action to depth of water, and to height and length of wave, is one that must be left to the mathematician, and is one with which I cannot pretend to grapple, the following experiments, though on a small scale, may be worth recording:—

Dried peas placed on a glass plate in a slight depression on a sandy bottom in 6-inch water were rolled off by waves about 12 inches long, and about 1 inch high. Although the motion was due to the waves, the fact that the peas were ultimately rolled off the plate was due to the difficulty of getting the glass perfectly level under water. Shorter waves $1\frac{1}{2}$ inches high had much less effect on them. A little sand that had collected on the glass was beautifully rippled with $\frac{1}{8}$ inch ripples; these were dried and varnished. As it was difficult to discern slight motion of any object owing to the undulation of the water, I proceeded to make a rough indicator, whereby a vane of thin wood placed at the bottom at right angles to the course of the waves would communicate a multiplied motion to a long light needle above the surface.

With this rough machine I tried the following experiments:—

(1.) Water, 8 inches; to top of vane, 7 inches. Waves, 90 per minute; motion by indicator very marked.

(2.) Waves, 115 per minute, half inch high; motion doubtful.

(3.) Waves, 86 per minute, 1 inch high; motion at bottom very strong; index striking both checks.

(4.) Waves, 80 to 90 per minute $\frac{3}{8}$ of an inch high; motion at bottom strong.

This last experiment was an unintentional one. The larger waves had made a strand for themselves, and I found that by reducing the displacement of the wave generator, I could make smaller waves that, without altering the mean level of the water, rippled the lower part of the former strand which they by their smaller reflux failed to uncover. Thus by a slight alteration of adjustment of the generator, I could, by varying the height of the waves, form or destroy ripplemarks at pleasure. Whilst making these experiments, I chanced to

reduce the number of the low waves to between 80 and 90 per minute. These, though barely over $\frac{1}{4}$ of an inch in height, immediately affected the submerged vane, and the motion of the index attracted my eye, though I was not attending to it. On a subsequent occasion I found that waves between 80 and 90 per minute, and only $\frac{1}{8}$ of an inch high, moved the index at a depth of $6\frac{3}{4}$ inches, and moved flocculent matter on the sandy bottom at a depth of $7\frac{3}{4}$ inches.

In this experiment motion at the bottom was obtained when the depth was 62 times the height of the wave, though small in proportion to the wave-length.

If the evidence of the existence of alternate currents on the floor of shallow seas is strong; the evidence that the currents of power sufficient to roll and damage shells, are not constant currents, is still stronger. Molluscs, such as *pinna*, and *mya*, that have little, if any, powers of locomotion, could not coexist with currents capable of transporting in any quantity, even fine sand. They would perish, either from the destruction of their beds by the removal of the sand, or from fresh material being piled on top of them. Mr. Godwin Austen has well said, that a "drift-sand zone" is wholly unfitted for marine life.* But it is the drifting sand that is fatal, not the mere fact that the drift sand zone is the one that "comes within the range of the tidal and wave disturbance of the water." Off Paignton Sands in Torbay, the very zone described by Mr. Godwin Austen abounds in *Cardium tuberculatum* and *Donax vittatus*, but owing to the fact that the sands are open to heavy seas from one quarter only, they cannot drift, and the shells mentioned, as a rule survive the attacks of the waves, though many individuals succumb.

As ripple marks are formed under water, so also they can be preserved under water; and they are more likely to be there preserved than on a sea beach, where on the retreat of the tide, they are liable to be effaced by the very swell that has formed them.

In the case of a lake or sea, subject to slight changes of level, with a river running into it carrying mud or sand, we have all the conditions necessary for the formation and preservation of ripplemark. An occasional swell from the lake will ripple the submerged sand in the vicinity of the accumulating deposits brought down by the stream, and these will quietly cover up the ripples without effacing them. A slight rise in the level of the lake will shift the area of deposition further up the stream, and the bed that covered the ripples will in course of time be itself rippled, and in its turn covered up. In this manner a series of ripplemarks and beds of mud or sand often "false-bedded," may be rapidly formed, and in the case of increase of current as rapidly destroyed.

Ripples that have been left bare by the retreating tide, or possibly

* "Natural History of the European Seas," p. 233.

by the sinking waters of an inland lake or sea, may often be distinguished from those that have been formed and preserved under water. The former are usually imperfect through loss of their sharp ridges.* Occasionally in addition to this they form natural channels for surface drainage, and whilst their ridges are levelled, their furrows are deepened. This fact seems to be referred to by Dr. Geikie, in the third edition of his "Manual of Geology," where he points out, that owing to the ridges of fossil ripplemarks being often broad and equable while the intermediate furrow has a little channel; a cast can be distinguished from an original rippled surface, by the channel in the original surface producing a sharp little crest on the cast ("Man. Geol.," Jukes and Geikie, p. 172, 3rd Ed.).

The points that I have endeavoured to establish in the foregoing pages may be briefly recapitulated as follows:—Marine ripplemarks are formed by alternate currents set up by waves. Experiments with short high waves on a small scale prove strong action at a depth of half the wave-length, whilst the evidence of the marine fauna, and the testimony of nautical men go far to prove that ocean and channel waves strongly affect the sea bottom to at least the same relative depth. The depth at which proof of wave action can be forthcoming falls far short of that at which fine deposits can be rippled by currents incapable of leaving permanent traces in the damage done to shells.

It is scarcely necessary to point out that the subject treated of in the present paper, namely, the formation of ripplemark, is only one branch of a far wider and more important one, which for the sake of brevity, I have as much as possible kept in the back ground, namely, that of submarine denudation.

II. "Note on General Duane's Soundless Zones." By Dr. JOHN TYNDALL, F.R.S. Received March 21, 1882.

In reference to one of the powerful fog-whistles established on the coast of Maine, General Duane remarks as follows:—"The most perplexing difficulties, however, arise from the fact that the signal often appears to be surrounded by a belt varying in radius from 1 to $1\frac{1}{2}$ mile from which the sound appears to be entirely absent. Thus, in moving directly from a station the sound is audible for the distance of a mile, is then lost for about the same distance, after which it is again distinctly heard for a long time. This action is common to all ear-

* For an illustration of the former class see plate facing page 170 of "The World's Foundations," by Miss Agnes Giberne; and, for an illustration of the latter, see page 19 of Sir Charles Lyell's "Elements of Geology," 6th Edition. A.R.H., 4th May, 1882.